through a box is required, this method of filter change necessitates the use of multiple exhaust connections on the box. An out-of-box filter in the process of being removed from a system by the procedure illustrated in FIGURE 7.12 (step 3) is shown in **FIGURE 7.13**. It should be noted that this type of installation should not be used on future nuclear installations due to the potential for contamination release and cleanup.

For other methods where bagging does not block the airflow path (e.g., using the housings represented by FIGURE 7.8), but merely encapsulates the filter being removed or replaced, there is a dependence on the damper in the duct to prevent blow-by (leakage) during a filter change. In other methods, isolation dampers or valves are used to isolate the filter during a filter change. The filter housing is still adjusted to the glovebox to remain slightly negative in pressure. The technique of bagging filters from housings (FIGURE 7.8) offers protection only for local personnel and the service area where the filter mounting device is located. The side of the system downstream of the filter is protected not by bagging, but by leak-proof dampers and flawless handling of the dirty filter. Because any dislodged particles will be swept downstream when airflow is restored, downstream HEPA filters should be provided to intercept these particles.

7.5 GLOVEBOX SAFETY

The history of glovebox safety in the United States came about with the use of very unsophisticated gloveboxes of simple design for simple operations. These were "sandblasting- gloveboxes with and without filters. Some early gloveboxes were actually manufactured from plywood. Glovebox use evolved from the need for safe working environments and reductions in operator exposure. This evolution led to more complex gloveboxes and more complex problems. Most lessons learned were the result of accidental experiences. Simply put, many variables existed due to lack of experience with glovebox use. Through all of these experiences, much was learned about ergonomics, operator safety, the importance of training, and fire and explosion protection. Ergonomic problems related to handling material, performing service functions, and transfers were discovered early and are still a critical requirement in glovebox design. Operator safety has improved as a result of better glovebox designs with less operator intervention. Training has become a critical path from design through commissioning, operation, and decommissioning. Fire prevention is important enough that DOE STD 1066-99, "Fire Protection Design Criteria," Chapter 15,[30] was written for gloveboxes.

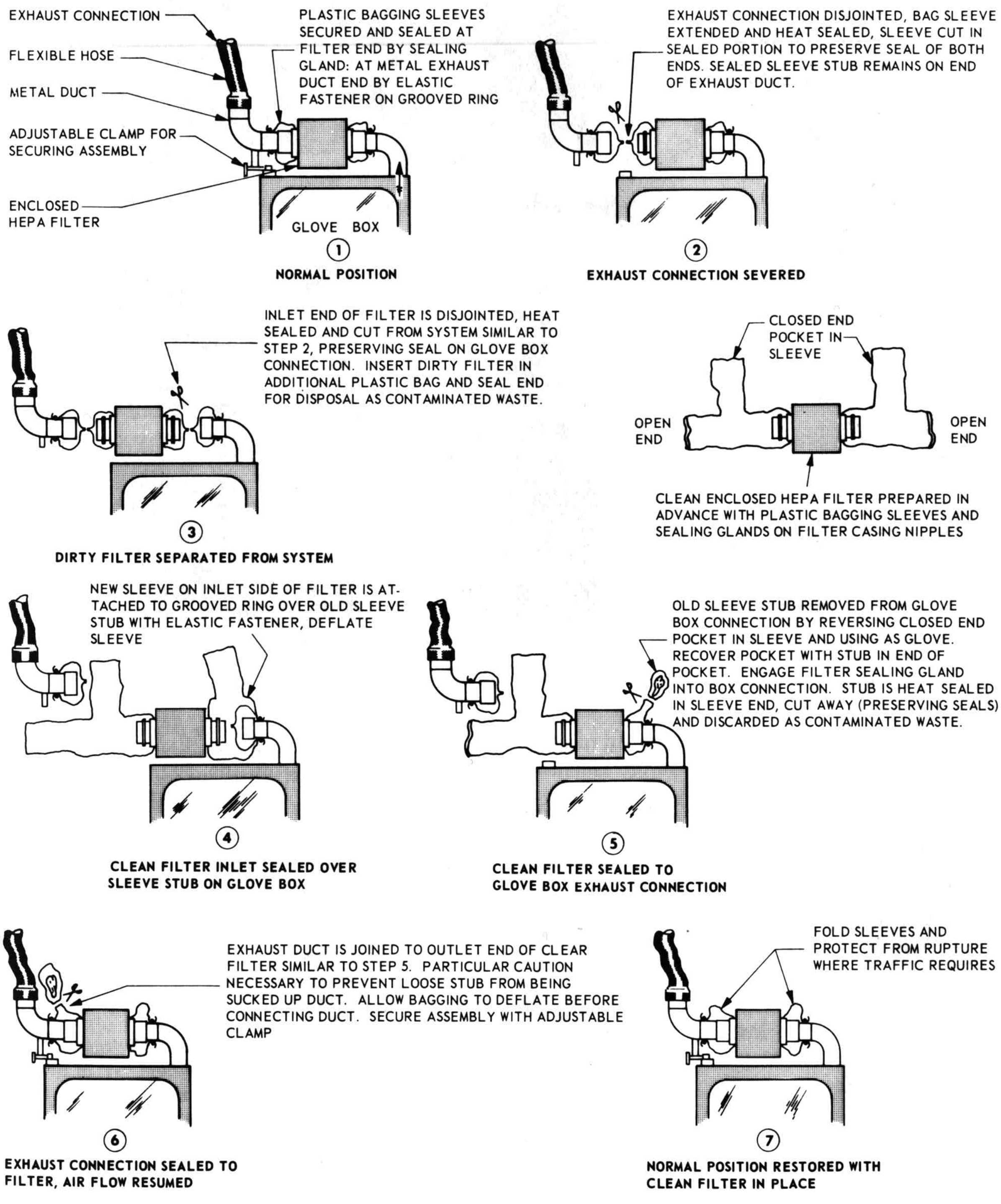

Figure 7.12 – Filter changing showing total containment

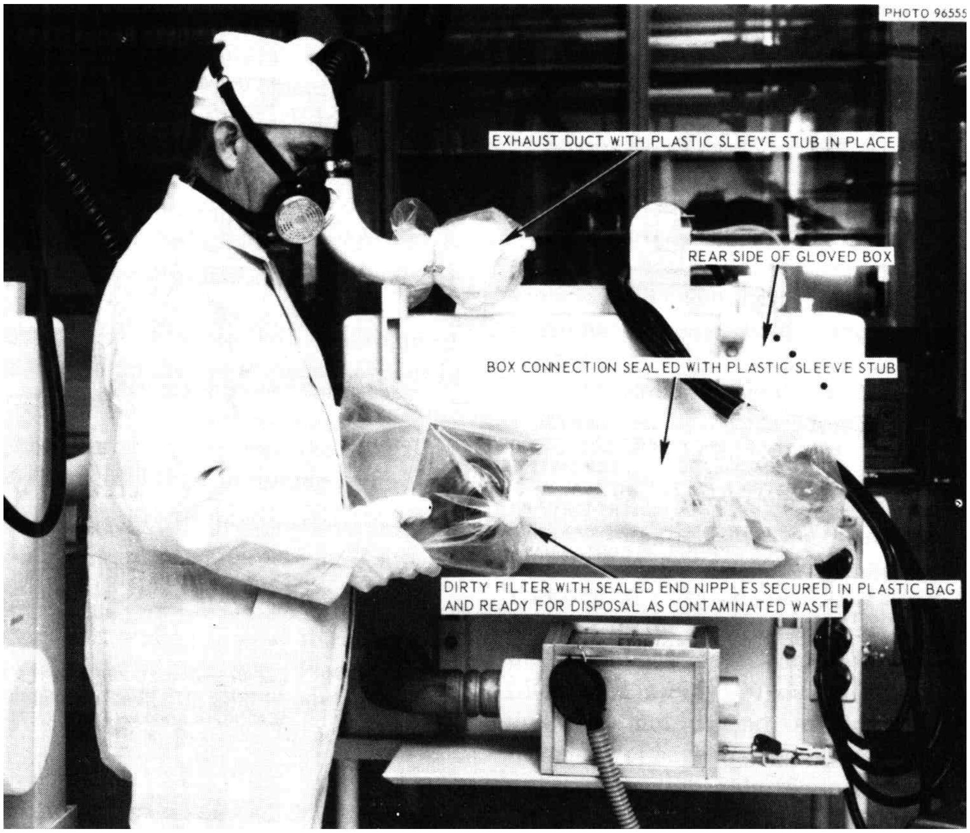

Figure 7.13 – Removal of out-of-box filter

7.5.1 PROTECTION AGAINST FIRE AND EXPLOSION

The current guidance for Fire and Explosion is given in DOE STD 1066-99.[30] This document outlines the requirements for glovebox applications needing fire suppression.

Fire Protection

In applications employing fire protection, the following principals are used:

- Use nonflammable materials as much as possible in construction. Gloves and windows are the most susceptible to fire due to the materials of manufacture. Laminated or tempered safety glass is the material of choice regarding fire. It should be noted that applications where explosion, overpressure, or moving or rotating machinery is a concern, impact-resistant, fire-retardant polycarbonate should be used to protect the worker. Some material hazards may also dictate the use of high impact material due to the hazards to the operating and maintenance personnel from a cracked or broken window. Some applications use a layer of glass located inside the glovebox as a solution.
- Strictly adhere to acceptable housekeeping practices. Spontaneous combustion of certain materials can occur in a glovebox as well as in the secondary work area.
- Avoid the use of flammable materials within the box wherever possible and limit the amount of flammable material to the calculated air change (Section 7.2.1) when no suitable nonhazardous substance can be substituted. Use containers for flammable substances that are "approved" for the planned operation.
- Maintain a current in-box material inventory. Gloveboxes should be used as designed. They are inappropriate for long-term storage, especially for chemicals (see Section 7.5.2).
- For inoperative gloveboxes, establish a safer, glovebox configuration and periodically check to make sure that these gloveboxes are in safe

condition. Precautions include isolating boxes by closing fire stops, checking through-flow, checking port covers, disconnecting electrical equipment, and removing corrosives.

- Design the box with downdraft ventilation (high air inlet, low outlet) if possible to inhibit combustion while still purging the box. Generation of light flammable gases by the process may dictate exhausting from the top.
- Provide a protective atmosphere (see Section 7.5.3). This measure is listed last because those preceding it are applicable to all gloveboxes, whereas inerting is used only when there is too much risk involved in operating without a protective atmosphere. Assessing the degree of risk involved in an operation is often a subjective evaluation.

7.5.1.1 DETECTION

A glovebox fire detection system is recommended when there is a high risk of fire determined by a Fire Hazard Assessment (FHA). If flammable solvents, coolants, packaging materials, etc., must be present during operation, and especially in unattended boxes, a heat detector should be installed on the glovebox. Fire detectors should be consistent with DOE STD 1066-99.[30] Fire detectors are required in plutonium gloveboxes due to the pyrophoric nature of the material.

7.5.1.2 SUPPRESSION

Since a fire within a glovebox may be of paper, chemical, electrical, or pyrophoric metal origin, there is no single suppression method that is best for all gloveboxes. This is discussed thoroughly in detail in DOE STD 1066-99,[30] however, when designing a glovebox, the designer should be aware of the materials, material quantities, process, and interfacing equipment that will be involved in the installation. At this point, the FHA should determine the proper suppression system for the installation. The fire suppression system must not cause a breech of the glovebox containment that can spread contamination and increase the personnel exposure hazard to an unacceptable level.

There is no assurance that filters will remain functional during and following exposure to fire, smoke, or burning debris. The temperature reached during a fire, the quantity and density of the smoke released, and the duration of the fire are variables to the destructive effects on prefilters and HEPA filters.

7.5.2 INERT ENVIRONMENTS

Inerting a glovebox environment is conducted when working with materials that are pyrophoric, oxygen-sensitive, or moisture-sensitive, or when a process must be protected. Inert gases such as helium, argon, and nitrogen are metered into a gas-tight glovebox to displace the "air" volume. The characteristics of the gas (lighter than air, heavier than air) are applied with proper sampling sensors used to obtain a true inerted glovebox. In pyrophoric and high-fire-potential applications, oxygen sensors are used to verify real-time concentrations. Inline filters should be installed to protect the oxygen monitor, as well as any monitor, from contamination. Monitors and sensors are available for many different types of gases and fumes. These should be selected when fire, explosion, and any associated risk to the process would result in danger to personnel and/or the facility. This should be determined by the facility risk and fire assessment groups. In most of these instances, the facility fire department should be directly connected to any alarms related to the event.

Gas-tight systems require quality construction of all components including gloveboxes, filters, and associated ducts. Any air ingress associated with the filter mounting or connecting duct will adversely affect the quality of the inert atmosphere that can be maintained in the glovebox and, therefore, the cost of inert gas purification. Penetrations used to pass electrical input/output signals and power into the glovebox should be hermetically sealed for this purpose.

In fire protection applications, the preventive step of inerting is safer, though more expensive, than extinguishing a fire if it does occur. However, oxygen must be reduced below 1 percent before it fails to support the burning of some pyrophoric metal.[9] The use of dry air (RH less than 20 percent) reduces the hazard of pyrophoric metal fires, but does not eliminate it. Moisture in the presence of heated pyrophoric or reactive metals, such as finely divided plutonium, increases the possibility of explosion by generating hydrogen.

The suitability and cost of an inert gas for the process are significant factors when selecting this type of fire control. The gas flow rate in most inert gas boxes is generally low. The flow must be consistent with required box-atmosphere purity levels, the scrubber, or the inert gas purification system that supports it. The inert gas may be purged on a once-through basis or recirculated through a purification unit. Purification, scrubbers, etc., should be protected with HEPA filters. Some of these systems are equipped with filters; however, it should be noted how the filter is safely changed while maintaining a level of containment. Gloveboxes usually have filters installed for this purpose, the designer should assess the potential for equipment contamination and cleanup.

7.5.3 Control and Instrumentation

Glovebox instrumentation may range from simple indicators and alarms to sophisticated control systems. The type of control or instrument used will depend on the characteristic(s) to be monitored, the relative hazard(s), and the method and time available to correct an upset condition. Operational characteristics to be measured and alarmed should always include the differential pressure between box and surroundings, the filter resistance, the gas flow rate through the box, and the box atmospheric temperature. An alarm should be available for any activity that could lead to degradation of or loss of containment, fire, or any other safety concerns. In addition to instruments and sensors on the box, it may be necessary to indicate and provide for readouts and/or alarms at a central panel for oxygen content, liquid level, neutron flux, gamma flux, fire, or explosive gas mixture inside the box.

When for safety a monitored characteristic requires annunciation when the level of a monitored parameter passes some predetermined point, the alarm may be local. For example, an alarm may alert the operator to an upset condition (e.g., when the glovebox pressure differential becomes less negative than its design relative to the surroundings), or it may signal an annunciator panel in an adjoining "cold" area (e.g., by the entry door to the glovebox room, in a control room, or both. Standard operating procedures, as well as sufficient information on the current contents of each box, should be available to ensure evaluation of the hazard area when an alarm sounds and to aid in planning corrective action.

Minimum instrumentation for a glovebox ventilation system should include devices to indicate the differential pressure between the box and its surroundings, exhaust filter resistance, total exhaust flow rate, and exhaust air temperature. **FIGURE 7.14** shows the arrangement of indicating devices in a glovebox ventilation system. The items shown above the double-dashed line indicate the types of instruments commonly used to supplement the minimum instrumentation necessary to improve safety for a particular operation or circumstance. For example, when box operators are not in full-time attendance for a continuous process, a sensor can be provided to monitor abnormal pressure, temperature, or most any other critical process monitoring and to actuate a remote alarm where an attendant is stationed.

FIGURE 7.15 shows a typical local mounting for a differential pressure gage (commonly referred to as a magnehelic gage) on top of a glovebox. The instrument should be mounted near eye level, and the indicating face should be located so that the operator has a clear view while manipulating the gloves. Gage display shall be such that operating conditions are easily discernable to the operator (for example: magnehelic gage with a range of 1 in.wc with "0" at the top). Sensing lines should be short and sloped directly back to the glovebox so that moisture will not pocket in the tube. Inline HEPA filters either should be inside or as close to the glovebox as possible to prevent contamination migration into the gage lines and gage. Tubing should be at least 3/16 in.-diameter to allow the instrument to respond quickly to rapid changes in pressure. Use of a three-way vent valve at the gage permits easy calibration (zeroing) without disconnecting the sensing tube. Calibration of glovebox differential pressure gages should be done routinely.

Selection of a magnehelic gage, photohelic gage, or transducer should be determined by the application. One advantage of using a gage is simplicity. A line is connected across the upstream plenum and downstream plenum of a filter where the pressure drop can be measured. Most gages and transducers install in this manner. A photohelic gage has the addition of an alarm

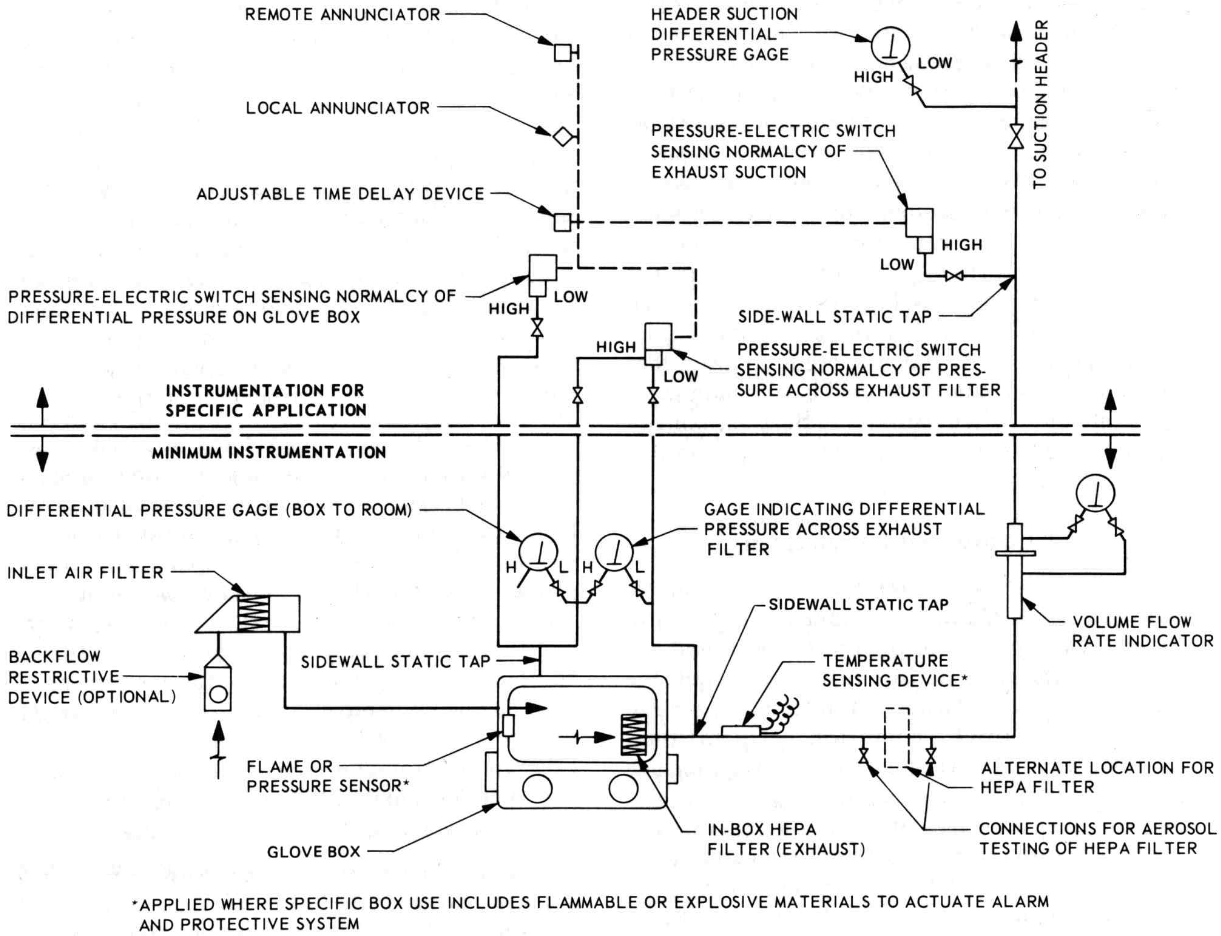

Figure 7.14 – Arrangement of indicating devices in glovebox ventilation system

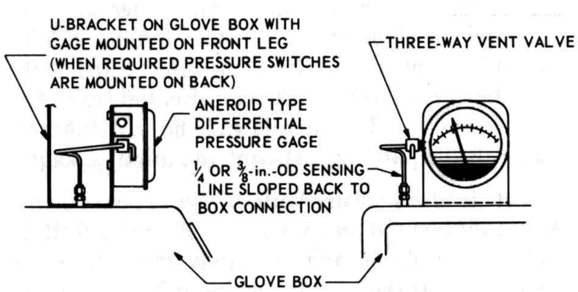

Figure 7.15 – Typical local mounting for differential pressure gage

function. A transducer allows multiple readouts and greater accuracy, and can be used to automate the exhaust system. It is more costly, however, because it must have a power supply, readout, and transducer. The requirement for a gage should be based on the actual system pressure. Exhaust filter pressure drops, for example, can vary up to 3 in.wg. Section 7.2 states that, if the inlet filter housing valve is closed, the device will see the full negative capacity of the blower. The gage or transducer must have a proof pressure greater than the maximum system pressure (negative or positive) so that it will not be damaged by excessive pressure. Devices that measure pressure have a problem with "drift." This occurs on most devices because of continual pressure on the device. As a result, they must be recalibrated on a routine schedule. Liquid-filled devices (manometers) are not recommended for glovebox pressure indicators, however, they have been used to check the calibration of an existing device. Inlet filters on air-ventilated gloveboxes generally do not require differential pressure gages. The pressure drop across the inlet filter is approximately the same as the box pressure.

A differential pressure gage should be provided for each exhaust HEPA-filter stage to indicate filter resistance. Pressure-sensing connections can be provided to permit the use of portable instruments. Suitable alarms or controls that can function on small pressure differentials (equal to 0.25 in.wg) are difficult to keep calibrated and are often expensive. **FIGURE 7.16** shows a method of indicating pressure drop through a filter. Section 5.6 gives further information on differential pressure instrumentation.

Instruments used to measure airflow rates from gloveboxes include an orifice plate, venturi meter, flow nozzle, and calibrated pitot tube. The important point is to use a simple, trouble-free device that gives reliable readings within an accuracy of ±15 percent. When free moisture is absent, a pitot tube is the least expensive and most adaptable device for the small volume flow rates associated with glovebox ventilation. Velocity pressure measurements (corrected for pitot-tube single centerline location[26]) for airflows and duct sizes common in glovebox applications are given in **FIGURE 7.17**. The corrections shown are for air at 60 degrees Fahrenheit and 14.7 psia, and neglect the pitot-tube coefficient. Pilot tubes are available with coefficients of 1.00, but there is an advantage in using the more common commercial pitot tube with a coefficient of 0.825 at low flow velocities. The equation for measuring velocity with a pilot tube is shown below.

$$V = K\,(2gh)^{1/2} \qquad (7.5)$$

where

V = fluid velocity, ft/sec

K =coefficient of the pilot tube

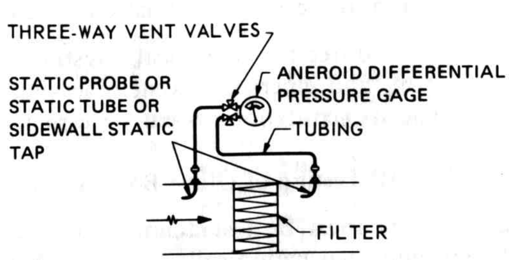

Figure 7.16 – Indicating pressure drop through a filter

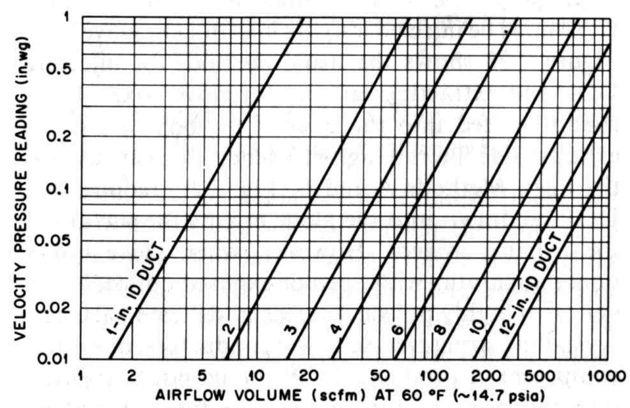

Figure 7.17 – Velocity pressure measurements

g = acceleration of gravity, 32.17 ft/sec^2

h = velocity pressure (ft) of the air-gas stream

The following equation is used for air at standard conditions:

$$V = 4005\,K\,(h_w)^{1/2} \qquad (7.6)$$

where

V = fluid velocity, fpm

h_w = velocity pressure, in.wg.

A pitot tube with a coefficient of 0.825 has a velocity pressure reading that is 1.47 times the velocity pressure reading of the pilot tube with a coefficient of 1.00 for the same fluid velocity. This pressure differential allows the low velocities often encountered in glovebox ventilation to be measured more easily.

FIGURE 7.18 shows the arrangement of a round orifice in a straight section of metal duct. Either method (pitot tube or orifice) can be used to read the flow volume directly on a properly calibrated gage. For a thin, square-edge, round, concentric orifice with the properties given in **FIGURE 7.19**, the flow rate can be determined with sufficient accuracy for glovebox applications by the following equation:

$$Q = 14d^2h^{1/2} \qquad (7.7)$$

where

Q = airflow, cfm

d = orifice diameter, in.

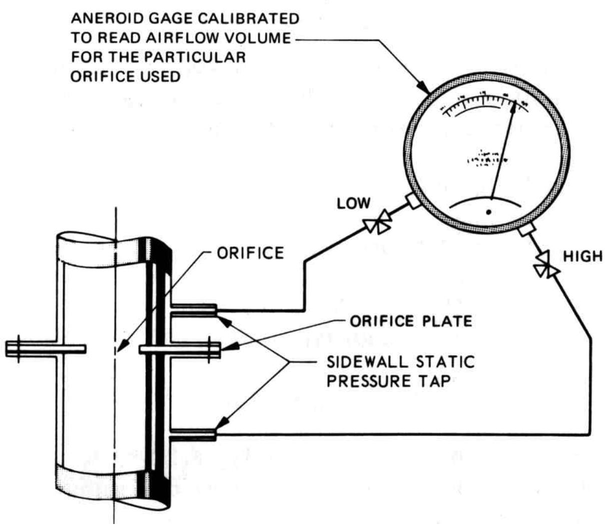

Figure 7.18 – Orifice meter method of measuring volume flow rate in small ducts

h =pressure drop across orifice, in.wg

Assumptions inherent in the constant 14 used in Equation (7.7) include (1) air at standard temperature and pressure, (2) flow coefficient for orifice = 0.65, and (3) ratio of orifice diameter to smooth-duct diameter, *D,* = 0.2 =*d/D =0.7.* The practical use of this formula can be shown by the following example.

Determine the orifice size necessary for a 20-cfm airflow rate that would give a reading near the center of scale on a 0- to 0.50-in.-range gage.

$Q = 20$ cfm

$$h = \frac{0.50}{2} = 0.25 \text{ in.wg}$$

$$d = \frac{Q}{14h^{1,2}} = \frac{20}{14(0.25)^{1,2}}$$

$d = 1.79$ in.

For 3-in. schedule 10 stainless steel pipe (3.260-in.-diameter), the *d/D* ratio is 1.79/3.26 = 0.55, which is within the acceptable range.

A shortcoming of the thin-plate orifice is loss of head of the air flowing through the device. The following tabulation gives the loss of head of concentric orifices for various *d/D* ratios.

Table 7.2 – Loss of head for various d/D ratios

/D ratio	Fraction of velocity head not regained
0.2	0.95
0.3	0.89
0.4	0.83
0.5	0.74
0.7	0.53

In the example above, 0.70 × 0.20 = 0.14 in.wg is the pressure loss when 20 cfm flows through the orifice of *d/D* = 0.55.

Immediately after installation, while filters are still clean, the measured pressure drop across the HEPA filter can be used to check airflow to a high degree of accuracy by proportioning the measured pressure drop to that stamped on the filter case at the time of predelivery testing. The pressure drop across the filter is no longer a dependable indication of gas flow rate after the filter has accumulated dust. After a filter has been in service for a period of time, it is necessary to measure both the pressure drop across the filter and the airflow through it to evaluate the filter's status and relationship to the whole ventilation

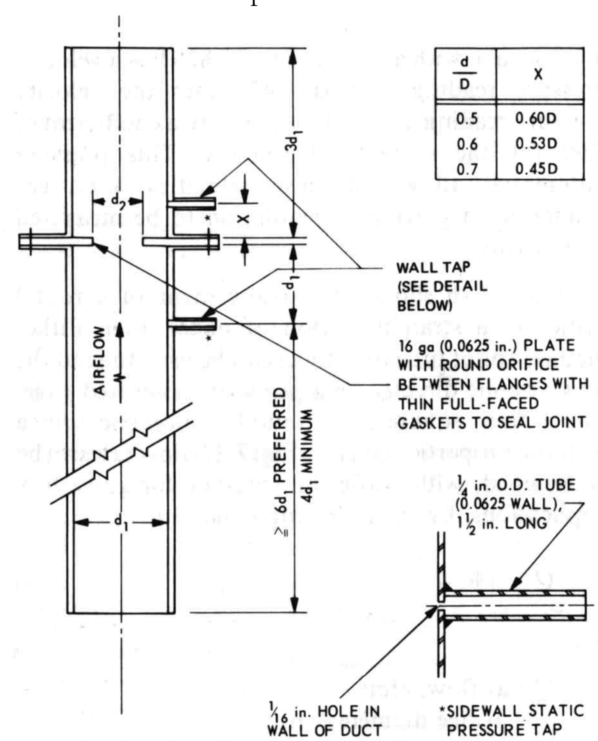

Figure 7.19 – Arrangement of sharp-edge concentric orifice in small duct

system.

Written procedures for periodically testing each alarm, control, and emergency system serving the glovebox and its ventilation system are essential.

7.5.4 Test Aerosol Testing of Glovebox Filters

HEPA filters must be tested immediately after installation and then periodically to assure that air cleanup capability and containment integrity remain intact. The principles of test aerosol testing of HEPA filters are given in Chapter 8. The HEPA filters used in glovebox systems are often inconvenient to test because the test aerosol must be injected into the inlet duct or glovebox. The test aerosol cannot be fed into the inlet of the box to test the exhaust-side filters if high-efficiency filters are used in the inlet. Methods A and B (**FIGURE 7.20**) require the test aerosol to be drawn into the glovebox by the suction of the exhaust system. However, the test aerosol should not be injected into gloveboxes housing apparatus with open or exposed optical lenses and with highly polished surfaces, delicate balances, crystalline structures, sensitive conductors, or

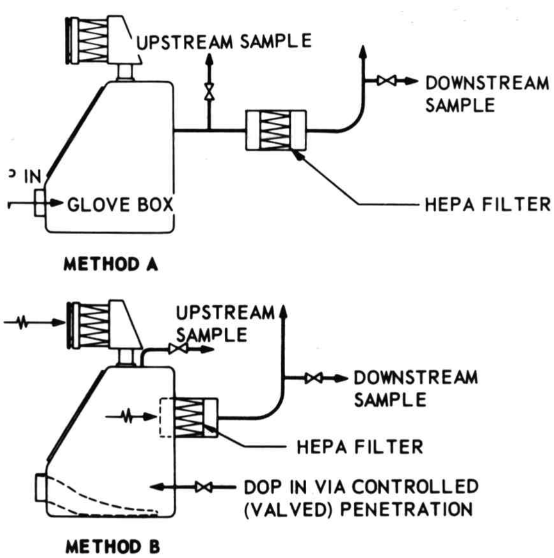

Figure 7.20 – Methods of injecting test aerosol and extracting samples (method A and B)

similar equipment or products. In such cases, the filter should be installed in the duct downstream of the glovebox so that the injected test aerosol

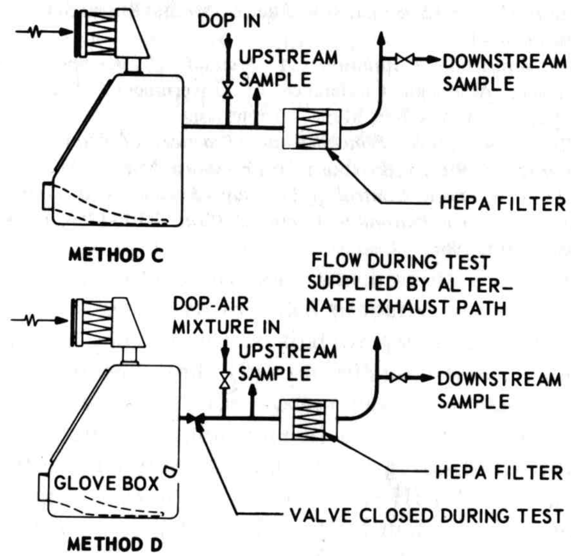

Figure 7.21 – Methods of injecting test aerosol and extracting samples (method C and D)

will not back up into the glovebox proper. Method C (**FIGURE 7.21**) may then be used for test aerosol testing of the exhaust HEPA filter.

Where new or replacement exhaust filters are required to be tested before restarting the ventilation system, method D (FIGURE 7.21) may be used. Note that in this method the exhaust path from the glovebox is closed and the test aerosol-air mixture for filter testing is drawn from a separate valved path. The side path is closed and sealed after testing is completed.

Methods A and B (FIGURE 7.20) require injection of the test aerosol-air mixtures into the glovebox via some convenient opening. A glove port can be used if containment is not critical during testing. Otherwise, a connection can be prepared (**FIGURE 7.22**) or an alternate method can be devised. Methods C and D (FIGURE 7.21) do not require the introduction of test aerosol into the glovebox. The test aerosol inlet connection must be sized to pass the test aerosol or test aerosol-air mixture. The connection for concentrated test aerosol in method C must admit 2 to 5 cfm, while the connection in method D must accommodate the total test aerosol-air mixture used for the test.

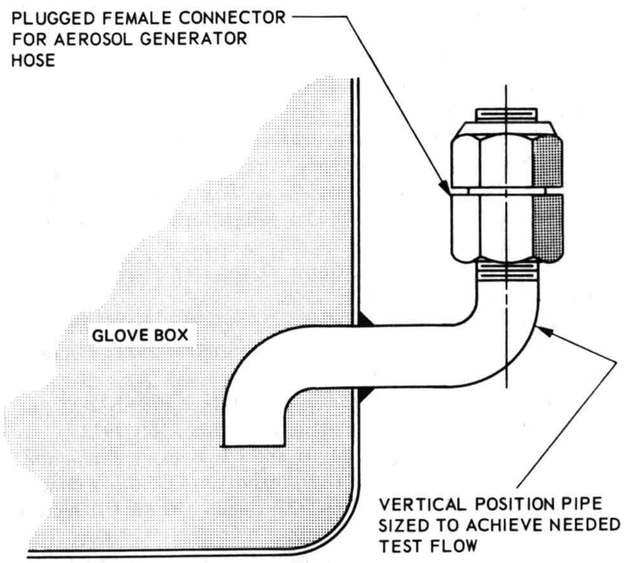

Figure 7.22 – Connection for introducing DOP into glove box

7.5.5 Glove-Box Shielding

Some gloveboxes may require gamma, beta, and neutron shielding because of the nuclides used and the amounts of material involved. Boxes handling kilogram quantities of plutonium can be shielded by providing lead-impregnated gloves, glovebox shielding (water or any other similar mass), lead glass over the windows, and lead-hinged plugs or covers over the ports.[27] The operating, shielding, removal, and replacement requirements of the glovebox HEPA filter must also be considered when glovebox shielding is required. The thickness of the shielding affects the design of the filter housing used on this type of glovebox. The designer should account for this by extending the service fittings (pressure measurement) and any other glovebox pass-through used in the design. This practice is also mandated for bagging ports used to remove the primary HEPA filters and the cover doors. Ergonomic operations inside shielded gloveboxes should be given careful consideration because lead-lined gloves and dimensional differences make manipulations very difficult.

7.6 References

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